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(54) [Name of the invention] Rolling mill roll

(Abstract)

(Problem to be solved) To obtain hot rolling mill rolls with good wear, seizure, surface roughening resistance.

(Solution) A material to make an external layer of the rolling roll contains (by weight percent) 2.0-3.8% C, 1.0-3.5% Si, 0.1-2.0% Mn, 0.5-10.0% Ni, 7.0-15.0%, 6.0 or less Mo, 6.0% or less W, less than 1.0% V, and 10.0% or less (including 0%) Co, and the balance substantially composed of Fe, and the formulae  $C - (0.7V + 0.3Mo) \geq 1.0$  and  $2.0 < Ni + Co < 10$  will be satisfied. Also, crystallized graphite is dispersed in the structure.

(Claim 1) The material for external layer of rolling roll contains (by weight percent);

C: 2.0-3.8%, Si: 1.0-3.5%, Mn: 0.1-2.0%, Ni: 0.5-10.0%, Cr: 7.0-15.0%, Mo: 6.0% or less, W: 6.0% or less, V: less than 1.0%, Co: less than 10.0% (including 0%), the rest is primarily iron, and also satisfy the formulae:

$$C - (0.7V + 0.3Mo + 0.2W) \geq 1.0,$$
$$2.0 \leq Ni + Co < 10.0$$

The microstructure of the roll is characterized by the dispersed graphite.

(Claim 2) a rolling roll using steel as inner portion fuses with external layer to form a solid piece.

[Detailed description of the invention]

[0001][Invention related technical field]

[0002]

[Current technology] For hot rolling roll, the external material should have good surface roughening resistance, wear resistance and anti-accident resistance etc. Japan patents 1-96355 and 2-88745, and International Patent W088/07594 disclosed high carbon high speed steel type cast iron materials. High speed steel type cast iron, containing a certain amount of Cr, Mo, W, and V, has excellent wear resistance under high temperature and is suitable for making hot rolling roll external layer.

[0003]

[Problem to be solved] However, the very hard MC type carbide is the major hard phase in these alloys, because of the huge difference in hardness between matrix and carbide, the matrix will be worn away first and leave the carbide to protrude from the surface, which will result in an increase in frictional coefficient or carbide falling off from the matrix to worsen the surface roughening resistance. On the other hand, the wear resistance, heat resistance, and surface roughening resistance are not very satisfactory in high speed type cast iron with precipitated graphite, as

disclosed in Japan Patents 1-287248, 7-6030, and 8-209299.

[0004] Hence, the objective of the present invention is to provide a rolling roll with excellent wear resistance, oxidation resistance and surface roughening resistance in order to solve the problems in previous rolling rolls.

[0005]

[Solution] The rolling roll that can solve previous problems is composed of (by weight percent): C: 2.0-3.8%, Si: 1.0-3.5%, Mn: 0.1-2.0%, Ni: 0.5-10.0%, Cr: 7.0-15.0%, Mo: 6.0% or less, W: 6.0% or less, V: less than 1.0%, Co: less than 10.0% (including 0%), the rest is primarily iron, and also satisfy the formulae:

$$C - (0.7V + 0.3Mo + 0.2W) \geq 1.0,$$

$$2.0 \leq Ni + Co < 10.0$$

The first characteristic of the invention is the existence of dispersed graphite in the microstructure and the second characteristic of the invention is to use steel as inner portion material to fuse with external layer to form a solid piece.

[0006]

Rolling roll made from present invention as external material has excellent wear resistance and the rolled material also shows good heat and surface roughening resistance as well. The external layer formed by the invention has dispersed  $M_7C_3$  type eutectic carbide with reduced amount of MC type carbide. Material having  $M_7C_3$  type carbide as primary alloy carbide can improve wear resistance and toughness and also increase seizure resistance and surface roughening resistance due to a lower frictional coefficient. Because graphite dispersedly precipitates in the microstructure, its lubrication effect can lower down frictional coefficient and therefore increase seizure resistance, which is especially useful to make hot rolling rolls with excellent properties.

[0007]

Based on the second characteristic of the invention plus the effects of the first characteristic of the invention, using steel as inner portion material combines the good wear resistance of the external layer material with the excellent toughness of the inner layer to form a rolling roll with excellent anti-accident property and good toughness.

[0008]

The reasons for the chemical composition ranges of the invention are given below;

[0009]

C is higher than 2.0% but less than 3.8%. Carbon combines with Cr, Mo, W, and V to form hard carbides like  $M_7C_3$ ,  $M_2C$ ,  $M_6C$ , MC to increase wear resistance of the rolling roll. There is not enough carbide if carbon is less than 2.0%. On the other hand, when carbon is higher than 3.8% excessive amount of carbides will decrease both toughness and thermal crack resistance. So the upper limit of carbon is 3.8%, preferred between 2.2-3.5%. Carbon should also be controlled for obtaining both graphite and carbide according to formulae

$$C - (0.7V + 0.3Mo + 0.2W) \geq 1.0$$

[0010]

Silicon is between 1.0 and 3.5%. Silicon is the necessary element to ensure good fluidity and to promote graphite precipitation. There is no desired effect when silicon is less than 1.0%; On the other hand, excessive graphite will increase wear rate because graphite can be the starting point to wear. Therefore, silicon is between 1.0-3.5%, preferred in between 1.4-3.0%. To promote graphite precipitation effectively, silicon content should be controlled lower and then add silicon to the required level as inoculation before pouring.

[0011]

Manganese content is higher than 0.1% and lower than 2.0%. Manganese has a hardening effect and can also combine with sulfur to form MnS, which is an effective element to prevent material brittleness caused by sulfur. On the other hand, too much manganese will deteriorate toughness of the material. Hence manganese should be between 0.1-2.0%, preferred between 0.4-1.2%.

[0012]

Nickel is higher than 0.5% and lower than 10.0%. The purposes of adding nickel are to strengthen the matrix and to promote graphite precipitation. There is no obvious effect if the amount of nickel is less than 0.5%; On the other hand, there will be too much graphite causing an increase in residual austenite and reduce anti-accident resistance as well as wear resistance when nickel is higher than 10.0%. Therefore nickel should be between 0.5-10.0%, preferred between 1.5-6.0%. Furthermore, when Ni+Co is less than 2.0% there is not enough graphite obtained while graphite promotion effect will saturate if Ni+Co is higher than 10.0% resulting in an increased amount of residual austenite to decrease both wear resistance and anti-accident ability. Therefore it is necessary to meet the formulae

$$2.0\% \leq Ni + Co < 10.0\%$$

[0013]

Chromium is higher than 7.0% and lower than 15.0%. Chromium combines with carbon to form high hardness  $M_7C_3$  type eutectic carbide to get high wear resistance and high toughness. Chromium partially dissolves into matrix to strengthen it through solid solution hardening mechanism. Moreover, comparing to previous high speed steel type cast iron containing MC type carbide, the present invention using  $M_7C_3$  as primary carbide has a lower frictional coefficient to improve seizure resistance and surface roughening resistance. However, there is no such an effect if chromium is less than 7.0%; there will be excessive amount of carbide and the carbide will become coarse, resulting in a lower toughness and thermal crack resistance when chromium is higher than 15%. Hence chromium should be between 7.0-15.0%

[0014]

Molybdenum should be less than 6.0%. Molybdenum forms  $M_6C$  and  $M_2C$  type carbides and molybdenum can raise both room temperature and high temperature hardness to increase wear

resistance. However, it is difficult to obtain the expected amount of graphite if molybdenum content is too high. Hence the upper limit is 6.0, preferred between 2.0-4.0%.

[0015]

Tungsten should be less than 6.0%. Tungsten can also combine with carbon to form  $M_2C$  and  $M_6C$  type complex carbides to increase both room temperature and high temperature hardness and therefore improve wear resistance. However, excessive amount of tungsten will reduce the amount of graphite precipitated. Therefore, the upper limit for tungsten is 6.0%, preferred between 1.0-3.0%.

[0016]

Vanadium should be less than 1.0%. Vanadium can easily combine with carbon to form MC type carbide to increase wear resistance. However, too much vanadium will cause carbide segregation and also greatly retard graphite precipitation. Therefore, vanadium should be less than 1.0%, preferred between 0.5-0.9%.

[0017]

Cobalt content should be less than 10.0% (including 0%). Cobalt dissolves in the matrix as solid solution atoms, which can increase matrix hardness and also increase solubility of Cr, Mo, and other carbide forming elements in the matrix under high temperature. As a result, the alloy will precipitate more secondary carbide during tempering to improve wear resistance. This effect will be saturated when cobalt is beyond 10%. Hence cobalt content is between 0-10.0%, preferred between 0-7.0%. Furthermore, cobalt is also a graphite promotion element, cobalt content should satisfy the formulae to ensure enough graphite,

$$2.0 \leq Ni + Co < 10.0\%$$

[0018]

The alloy in the present invention can be quenched and then tempered to control microstructure and hardness as well as remove internal stress. For example, quenching can be done at above 950 °C and below 1100 °C and tempering at above 500 °C and below 600 °C.

[0019]

[Example] The actual example of the present invention is illustrated below. Figure 1 is the actual chemical compositions poured. Quench these samples at 950-1100 °C, then temper at 500-600 °C to control microstructure and hardness as well as to remove the residual stress. No. 1 through No. 5 are inventive examples of the rolling roll materials for external layer and No. 6 to No. 9 are previous high speed steel type cast irons.

[0020]

In order to evaluate these experimental materials, seizure, hardness, carbide area, and wear tests were carried. The results are listed in figure 2, where carbide and graphite area is determined by EPMA image analysis. Friction and wear tests are done under the following conditions, and the condition for seizure test is also given below;

### Friction and wear tests

Testing temperature: 300 °C

Applied load: 5 kg/cm<sup>2</sup>

Rotation speed: 100m/min

Sliding distance: 20000 m

### Seizure resistance test

Testing method: KF type seizure tester

Sample dimension:  $\phi 10 \times 32$  L

Material rolled: SUS304

Rotational speed: 284 rpm

[0021]

From Figures 1 and 2, the amount of graphite increases with increasing in nickel content though silicon also increases, and the increase of the amount of graphite lowers down friction coefficient and improves seizure resistance to reach the objective of improving surface roughening resistance and seizure resistance of high speed steel type cast iron rolling roll materials. In the inventive examples, compared to No. 1 and No. 2, No.3-No. 5 have higher amount of  $M_7C_3$  and graphite, and therefore better results in hardness, frictional coefficient, wear resistance, seizure resistance as well as oxidation resistance.

[0022]

[Advantages of the invention] In claim 1 the external layer, made from the above alloy, of a composite roll has excellent wear resistance and also provides better seizure resistance and surface roughening resistance. By dispersing primary  $M_7C_3$  type carbide and reducing MC type carbide, the wear resistance and toughness have been improved while a lower frictional coefficient improves seizure resistance and surface roughening resistance in the inventive alloy. On the other hand, the precipitated graphite dispersed in the microstructure can reduce frictional coefficient to enhance seizure resistance. These improvements will provide a hot rolling roll with excellent properties. Furthermore based on claim 1 and claim 2 the inner steel portion fuses with external layer, which can combine excellent wear resistance of the external layer and the good toughness of the inner layer to form a hot rolling roll with excellent anti-accident and toughness properties.

[Brief description of the graphs]

[Figure 1] shows the inventive examples of No. 1 to No. 5 and the comparative examples of No. 6 to No. 9.

Figure 2 shows the test results.